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Chip-Scale Atomic Devices: Precision Atomic Instruments based on MEMS

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Since 2001, there has been considerable effort directed toward the development of atomic frequency references based on microfabrication techniques[1]. We describe efforts at NIST to adapt technology and processes developed in connection with these "chip-scale" atomic clocks to other compact atomic instruments such as magnetometers, gyroscopes and optical wavelength references. The core technology used in all of these instruments is the microfabricated alkali vapor cell[2], which allows the confinement of alkali atoms in sub-millimeter structures fabricated from glass and silicon. In addition to small size, and corresponding low power requirements, these cells could be fabricated in arrays on a single wafer at low cost and easily integrated with other wafer-based optical components.

Magnetometers based on these MEMS alkali vapor cells have demonstrated a sensitivity of 6 pT/√Hz near earth's field and 70 fT/√Hz in a low-field magnetically shielded environment. The earth's-field sensor[3] was based on the traditional Mx geometry with a physics package volume of 20 mm^3 and a power requirement of 195 mW. The low-field sensor[4], implemented with a MEMS vapor cell in a table-top optical setup, was based on the spin-exchange relaxation-free technique[5], in which spin-exchange broadening of the magnetic resonance is suppressed by operating at low magnetic fields and high alkali densities. We have additionally realized a "photonic" magnetometer physics package capable of both high-field and low-field operation and needing no electrical connections, requiring only optical signals to be transmitted to the physics package through fibers. Promising application areas for these sensors include biomagnetics, nuclear magnetic resonance, magnetic anomaly detection, aerial vehicle attitude stabilization and the measurement of magnetic fields in space.

Gyroscopes based on monitoring the changes in Larmor frequency of atomic spins in a rotating frame are also being developed in our lab. These instruments are based on polarized nuclei of noble gas atoms such as ^{3}He or ^{129}Xe. We have measured nuclear spin relaxation times approaching 10 s in ^{129}Xe confined in millimeter-scale cells, which suggests that gyroscopic sensitivities below 1 °/hr (~ 10^{-6} Hz) are feasible.

Finally, we briefly discuss other emerging areas of MEMS-based atomic instrumentation including mechanically resonant microstructures magnetically coupled to ensembles of atomic spins.

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